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Final Report

"Airborne Microwave Radio-
metric Data Analysis"

Contract No. NAS5-21674

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

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22 May 1972

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I. BACKGROUND

Attempts to measure soil moisture by microwave radiometry were made by the National Aeronautics and Space Administration (NASA) in a series of flights over the Imperial Valley of Southern California during 1968. A correlation was sought between brightness temperature obtained with a 19.35 GHz electrical scanning microwave radiometer and soil moisture estimated from infrared color prints and infrared Ektachrome transparencies which were taken at the same time. This data analysis appears in the Final Report for Contract No. NAS5-21612 entitled, "Airborne Microwave Radiometric Data Analysis," prepared in 1971. Recommendations in that report proposed, among other things, that future studies include ground truth data on soil moisture.

In 1971, NASA conducted a series of overflights at Imperial Valley, California; Phoenix, Arizona and Weslaco, Texas. On the day of the flights, ground crews collected soil samples and took notes on vegetation and soil conditions of selected fields along the predetermined flight path. Percent moisture in each of the samples collected was determined. Procedures for

soil collection and moisture analysis together with a compilation of ground truth data obtained during flights over Imperial Valley and Phoenix have been reported in the Final Report for Contract No. NAS5-21610 entitled, "Soil Moisture Ground Truth Data for Correlation with Microwave Radiation Data," also prepared in 1971.

This report contains the results from the 1.5 cm, 19.35 GHz electrical scanning microwave radiometer which was one of the instruments used during the 1971 flights.

II. METHODS OF ANALYSIS

Raw data collected during the flights were processed and analyzed by Biospherics Incorporated. The data included:

1. Computer printout of the microwave brightness temperatures,which corresponded to Greenwich mean time in seconds,and the radiometer scan angle.
2. Flight log from the Convair 990 flights.
3. I. R. transparencies taken at 10 second intervals from the Convair 990 and marked with Greenwich mean time in seconds. The camera angle was fixed perpendicular to the plane at level.
4. Irrigation and topographical maps of the test areas.

The procedure used to locate the microwave data with respect to designated areas on the ground was as follows:

1. The center of each I. R. transparency was located and a point corresponding to this center was made on topographic and/or irrigation maps. Connection of these points resulted in the flight path which corresponded to zero degrees of scan of the radiometer.

2. Each of the I. R. transparencies bears a Greenwich mean time designation; therefore, each point marked on the topographic or irrigation maps is assigned this time reference.
3. A scale corresponding in overall length to the distance between connective marks on the topographical or irrigation map (marks established by I. R. transparencies taken at 10 second intervals) was prepared. This scale was then marked at equidistant,one second intervals. Designated test fields could, therefore, be located with reference to a specific series of Greenwich mean time designations.
4. Perpendicular displacement of the designated test fields from the established flight path was measured on the map. This distance and the altitude of the plane, taken from the flight log, were used to calculate the scan angles of inclusion for the designated test fields.
5. The information obtained in Steps 3 and 4 was then used to outline the boundaries of

the field on the computer printout of the microwave data. These boundaries were further corrected by observation of irregularities such as buildings, standing water, etc., which occurred in the I. R. transparencies of the test fields.

An example of an irrigation map showing the flight path and designated test fields is shown in Figure 1. The location of microwave data on the computer printout which corresponds to these test fields is shown in Figure 2.

It should be noted that the flights conducted during 1971 were parallel to access roads and adjacent fields and almost directly above the test fields. This flight path greatly simplified the location of microwave data since these data now appeared in rectangular blocks rather than the skewed shapes determined in the 1971, NAS5-21612 Report. Fields directly below the flight path also provided the maximum number of microwave points per unit area field.

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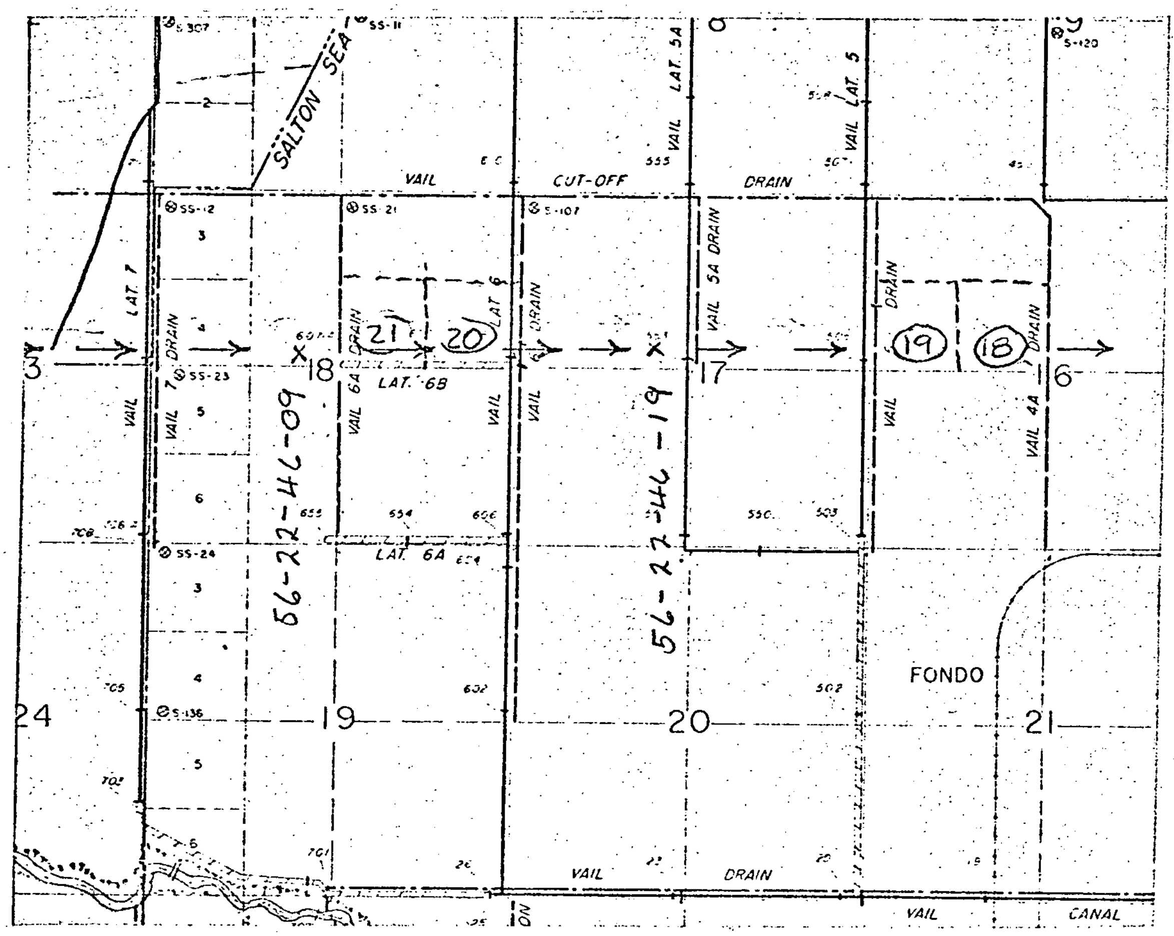

Figure 1

Irrigation Map of the Imperial Valley Showing Greenwich Mean Time Designations (X) Flight Path (——→) and Designated Test Fields (circled numbers)

FLIGHT 1A 02/25/71 19 GHZ RADIOMETER CALIBRATED BRIGHTNESS TEMPERATURES IN DEGREES KELVIN

DAY		56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
HOUR		22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
MIN		45	45	45	45	45	45	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
SEC		54	55	56	57	58	59	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	49.3	104	101	101	100	103	98	101	99	106	105	102	109	104	110	110	106	114	113	111	111	109	109	117	133
2	45.9	97	103	100	103	108	105	102	100	104	104	101	105	109	109	117	107	109	111	105	115	112	127	123	148
S 3 V	42.7	102	106	107	109	111	106	108	113	112	113	114	105	116	117	115	116	103	112	109	116	120	144	152	172
C 4 I	39.6	103	106	101	105	104	107	111	109	103	108	106	109	108	109	114	110	108	109	109	129	154	142	202	219
A 5 E	36.7	107	103	107	105	106	104	99	107	106	109	108	106	111	105	109	107	109	127	144	177	211	225	246	249
N 6 *	33.9	104	103	106	108	107	105	107	110	115	110	103	107	107	109	106	109	124	150	194	231	257	255	269	254
7	31.2	109	111	109	106	102	105	103	106	111	105	113	109	111	110	122	137	160	191	222	250	254	271	264	257
P 8 A	28.6	109	112	111	111	105	110	111	105	113	111	108	109	108	118	166	198	195	217	236	260	269	255	262	272
O 9 N	26.0	105	107	119	107	113	109	114	121	112	112	111	110	115	136	195	244	230	236	256	268	281	274	272	275
S 10 G	23.5	108	108	118	109	106	113	109	111	118	112	111	108	119	152	199	234	231	222	250	274	275	282	276	279
I 11 L	21.0	121	113	112	109	115	115	109	110	114	113	115	120	151	197	202	215	229	238	254	268	279	276	280	275
T 12 E	18.6	119	114	110	119	110	113	109	117	112	112	118	153	211	236	211	211	221	232	244	274	281	278	274	285
I 13	16.2	134	111	109	107	117	110	114	114	115	111	118	154	234	254	257	251	248	263	259	249	274	272	272	255
O 14 I	13.8	174	124	118	112	108	112	108	116	110	114	132	192	235	262	278	281	281	279	278	271	274	236	275	271
N 15 N	11.5	212	160	124	118	115	119	111	109	119	119	145	205	243	264	278	275	284	285	275	272	273	273	281	252
16	9.2	213	190	139	116	118	115	116	120	115	133	170	222	248	265	283	276	280	277	279	290	272	292	283	254
17 D	6.9	222	143	122	113	113	112	105	112	114	135	187	236	246	269	278	281	289	255	279	272	275	241	272	259
18 E	4.6	134	134	115	115	112	115	117	121	117	143	208	235	255	269	278	279	274	270	259	275	279	277	269	255
19 G	2.3	137	113	116	116	123	116	112	118	124	163	203	243	248	274	284	280	286	275	269	266	264	273	264	254
20 R	0.0	117	115	114	111	112	114	123	122	132	184	191	229	271	276	280	278	290	275	257	263	269	270	256	245
21 E	-2.3	115	119	115	123	121	125	121	121	161	208	185	200	260	278	278	276	277	275	263	265	241	264	243	257
22 E	-4.6	119	117	119	114	114	119	118	140	192	221	172	169	249	276	275	278	276	271	265	260	263	252	250	252
23 S	-6.9	117	117	115	112	116	117	122	161	225	238	172	196	253	277	280	274	292	267	262	257	271	242	260	251
24	-9.2	113	110	114	108	122	129	158	203	250	242	196	239	253	275	274	276	274	257	261	267	266	255	262	254
25	-11.5	117	115	116	117	157	232	250	259	269	267	254	260	255	276	278	271	279	270	256	270	265	259	252	245
26	-13.9	114	112	115	123	192	263	275	275	273	276	270	276	274	278	276	286	281	276	274	277	259	257	256	250
27	-16.2	115	113	112	149	235	264	293	275	280	270	269	273	292	276	278	270	290	277	281	272	274	244	253	243
28	-18.6	114	112	125	135	246	266	270	273	275	266	265	266	270	274	273	279	277	271	273	271	270	252	247	247
29	-21.0	175	121	155	226	265	269	280	272	269	270	272	274	276	279	279	275	281	275	271	269	275	253	244	249
30	-23.5	210	168	128	235	259	265	276	284	271	274	273	266	278	278	280	275	269	271	276	277	276	262	250	244
31	-26.0	157	218	223	228	265	269	265	266	265	264	266	274	291	272	277	278	267	277	280	275	245	252	263	259
32	-28.6	171	230	231	232	259	267	270	271	262	263	274	272	274	274	276	281	274	272	272	278	275	254	267	273
33	-31.2	179	241	252	232	232	244	251	257	255	271	273	277	277	290	278	276	279	275	273	271	273	273	259	273
34	-33.9	200	247	250	244	244	242	241	243	245	241	250	254	265	265	264	270	270	277	266	270	279	250	267	259
35	-36.7	239	253	262	236	252	243	248	261	252	243	256	259	271	262	258	262	251	255	262	272	259	254	255	259
36	-39.6	229	253	263	264	255	241	259	261	260	257	261	268	271	265	263	270	264	262	260	257	254	230	253	255
37	-42.7	205	249	262	265	255	246	259	261	262	261	263	267	262	267	271	276	273	271	261	255	253	246	255	251
38	-45.9	216	241	255	262	256	248	249	244	253	239	256	237	262	267	266	258	269	262	264	243	255	237	235	245
39	-49.3	245	244	243	248	249	239	239	243	244	244	249	259	250	255	262	265	262	261	258	255	247	245	241	245

CCM POSITION	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
CCM COUNT	483	388	478	1	478	91	476	45	478	376	478	0	473	388	475	1	476	91	480	48	477	376	472	0
ANALOG COUNT	169	177	174	170	482	531	476	498	963	480	0	0	170	177	175	169	480	524	474	498	961	480	0	0
AGC	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272	272
NADIR COUNT	331	335	338	341	340	337	325	326	314	247	238	189	134	128	122	123	121	129	148	143	137	134	139	165

COLD COUNT	478.5	478.5	478.5	478.5	478.5	478.5	475.5	475.5	475.5	475.5	475.5	475.5
ANTENNA TEMP	292.6	292.6	292.9	292.6	292.1	292.6	292.4	293.5	291.7	292.4	293.0	292.4
HOT LOAD TEMP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROLL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PITCH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ALT (FEET)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ALT (METERS)	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ROSEMOUNT TEMP	0	0	0	0	0	0	0	0	0	0	0	0
CALIB TEMP DIFF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 2

Computer Printout of Microwave Brightness Temperatures
(Two test fields and the Salton Sea are outlined.)

III. RESULTS

Brightness temperatures contained in individual fields were averaged and the standard deviation calculated. Appendix I of this report contains the data which were obtained during the 10,000 foot overflights of Phoenix and the Imperial Valley on 25 February 1971.

Brightness temperatures and soil moisture results obtained during 3,000 foot flights over Phoenix, Arizona; Imperial Valley, California and Weslaco, Texas are also included as Appendix II. These data were supplied by the Technical Officer, Dr. Thomas Schmugge at Goddard Space Flight Center.

IV. DATA CORRELATION

Computer analysis of the data was made to determine the correlation between microwave brightness temperatures and soil moistures.

A. All fields from Phoenix and Imperial Valley were assigned a 14-character descriptive code. The code provided a "yes" or "no" selection of test fields so that individual categories of fields could be correlated. The selection code consisted of the following criteria:

1. Bare
2. Vegetated (greater than 50 percent coverage)
3. Vegetated (less than 50 percent coverage includes young plants and stubble)
4. Leveled (includes disked, plowed, bordered, land planed)
5. Furrowed
6. Loam soil
7. Laveen loam soil
8. Sandy loam soil
9. Clay loam soil
10. Sandy clay loam soil

11. Soil moisture sampling done on the same day as the overflight

12. Cloddy (plowed fields were also assumed to be cloddy)

13. Imperial Valley

14. Phoenix

B. Computer cards were prepared for each field.

Each card contained the above selection criterion code and all soil moisture determinations and brightness temperatures which were obtained for that field. The following data was programmed:

Microwave Brightness Temperature

X_1 Phoenix, 3,000 ft. 2/25/71, 4:57 - 5:11 p.m. MST

Imperial Valley, 3,000 ft. 2/25/71, 2:15 - 2:34 p.m. PST

X_2 Phoenix, 10,000 ft. 2/25/71, 5:15 - 5:27 p.m. MST

Imperial Valley, 10,000 ft. 2/25/71, 2:45 - 3:01 p.m. PST

X_3 Phoenix, 3,000 ft. 3/1/71, 1:33 - 1:46 p.m. MST

Imperial Valley, 3,000 ft. 2/25/71, 5:00 - 5:25 p.m. PST

Soil Moisture

Y_1 Phoenix - samples collected on 2/23/71 or 2/25/71

Imperial Valley - samples collected on 2/25/71

Y_2 Phoenix - samples collected on 3/1/71

A computer tabulation of all data which were analyzed is included with this report as Attachment I. Plotting and statistical handling of the data were done by computer. A program was written which assembled all data corresponding to a requested selection code and provided the following:

1. Tabulation by field number of data which corresponded to the desired selection code.
2. X vs. Y plot of data including least square regression line.
3. Equation of the least square line including algebraic values necessary for calculation of the line.
4. Correlation coefficient.
5. Standard error of estimate.

Each computer plot has been given a two or three digit chart number which identifies the data group. The first one or two digits indicates the request number (see Table 1). The last digit indicates the X vs. Y data match.

Results of the completed statistical analysis of requests 1-16 are given in Attachment II and are summarized in Table 1. A good correlation between microwave brightness temperatures

Table 1

Correlation Coefficient for Selected Field Types

Request Number	1: 2/25/71 3,000 ft. $X_1 \times Y_1$	No. Observations & Range of Moisture	2: 2/25/71 10,000 ft. $X_2 \times Y_2$	No. Observations & Range of Moisture	3: 2/25/71 3,000 ft. $X_3 \times Y_1$	No. Observations & Range of Moisture	4: 3/1/71 3,000 ft. $X_3 \times Y_2$	No. Observations & Range of Moisture
1. Bare, sampled day of flight, Phoenix	-.84	(52) 2 - 33	-.12	(75) 2 - 29				
2. Bare, Imperial	-.50	(26) 6 - 36	-.27	(32) 4 - 36	-.46	(28) 6 - 36		
3. Bare, all fields at Phoenix	-.73	(100) 2 - 32	-.20	(162) 2 - 32			-.60	(103) 2 - 29
4. Bare, leveled, Imperial	Insufficient Data	(3)		(3)				
5. Bare, leveled, Phoenix	-.68	(61) 3 - 32	-.26	(90) 3 - 31			-.64	(62) 2 - 29
6. Bare, furrowed, Imperial	-.68	(13) 19 - 38	-.13	(15) 19 - 36	-.64	(15) 19 - 36		
7. Bare, furrowed, Phoenix	-.80	(39) 2 - 27	-.13	(72) 2 - 27			-.54	(41) 2 - 25
8. Bare, loam, Phoenix	-.64	(26) 2 - 26	-.35	(45) 2 - 25			-.68	(28) 2 - 20
9. Bare, laveen loam, Phoenix	+.32	(20) 4 - 11	-.40	(25) 4 - 11			-.86	(18) 4 - 18
10. Bare, sandy loam, Phoenix	-.91	(18) 3 - 22	+.27	(26) 2 - 22			-.53	(19) 2 - 19

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Table 1 (continued)

Correlation Coefficient for Selected Field Types

	1		2		3		4	
Request Number	2/25/71 3,000 ft. $X_1 \times Y_1$	No. Observations & Range of Moisture	2/25/71 10,000 ft. $X_2 \times Y_2$	No. Observations & Range of Moisture	2/25/71 3,000 ft. $X_3 \times Y_1$	No. Observations & Range of Moisture	3/1/71 3,000 ft. $X_3 \times Y_2$	No. Observations & Range of Moisture
11. Bare, clay loam, Phoenix	-.70	(33) 5 - 33	-.12	(53) 5 - 32			-.69	(33) 3 - 29
12. Bare, sandy clay loam, Phoenix	Insufficient Data	(3) 14 - 27	-.49	(10) 5 - 27				
13. Bare, cloddy, Phoenix	+.24	(19) 4 - 8	-.36	(24) 2 - 13				
14. Vegetated (> 50% coverage)	-.52	(18) 8 - 28	-.46	(21) 8 - 28				
15. Vegetated (< 50% coverage)	-.36	(13) 3 - 25	-.10	(24) 3 - 28				
16. Bare, cloddy, Phoenix							+.44	(19) 3 - 10

and soil moisture is given by a negative number which approaches -1.0.

Good correlation was obtained for the 3,000 ft. overflights. However, some selection criteria appeared to be better than others. Much better results were obtained at Phoenix than the Imperial Valley. Correlation data were also much better on 25 February 1971 when only the soil moistures from samples collected that same day were included.

Data collected at 10,000 feet showed little or no correlation and the presence of vegetation appeared to reduce correlation greatly.

In view of the fact that the 23 February 1971 sampled fields showed decreased correlation, it was decided that fields of a given surface and soil texture which showed the best correlation should be rechecked with the 23 February 1971 samplings excluded. The results of this second analysis are shown in Attachment III and are summarized in Table 2.

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Table 2

Correlation Coefficient for Selected
Field Types Sampled at Phoenix on 2/25/71

Request No.	Correlation Coefficient	No. Observations	% Moisture Range
17 Bare, furrowed	-0.87	(21)	1.9 - 27
18 Bare, leveled	-0.85	(31)	3.1 - 33
19 Bare, loam	-0.88	(13)	1.9 - 25
20 Bare, laveen loam	-0.29	(5)	3.9 - 8.4
21 Bare, sandy loam	-0.95	(8)	3.1 - 7.9
22 Bare, clay loam	-0.82	(25)	4.6 - 32.8

All field types showed improved correlation over that of the initial analysis. The soil surface configuration did not appear to affect the correlation coefficient which was -0.87 and -0.85 for furrowed and leveled fields respectively. Both of these field type groups contained approximately the same range of soil moisture. Of the four soil types which were compared, loam and clay loam showed correlation values similar to those obtained for the furrowed and leveled fields. The laveen loam and sandy loam showed correlation coefficient of -0.29 and -0.95 respectively. However, both of these latter groups had relatively few observations which represented only a narrow range of soil moistures. The correlation coefficient is probably indicative of scatter in the data.

Some of the data obtained during this study appeared to follow a biphasic curve. In some cases, soil moisture concentrations below ten percent did not appear to correlate as well with brightness temperature as those which ranged above ten percent moisture. It has been theorized that tightly bound water (a condition which occurs below the wilting point of soil) does not emit microwave radiation

similarly to unbound water. It might be expected, therefore, that the correlation between microwave brightness temperature and soil moisture would be better if only those fields containing unbound water were included in the analysis.

In order to test this possibility, an additional computer analysis was made in which soil moisture data of less than ten percent was rejected. The results of this analysis are shown in the computer printout (Attachment IV) and are summarized in Table 3. None of the field types showed significant improvement in the correlation coefficient and most showed decreased correlation. It appears therefore, either that the microwave brightness temperatures correlate at low soil moisture concentrations or that shortening the range of soil moisture values emphasizes scatter in data sufficiently to reduce correlation. At least for one field type (Charts 171 and 211, bare, sandy loam, Phoenix) shown in Figures 1 and 2, good correlation was obtained for low soil moisture fields. For these fields, the slope of the curve for soil moistures ranging from three to eight percent was very similar to the slope which occurred when the plot included fields of soil moisture which ranged from two to 30 percent.

Table 3

Correlation Coefficient for Selected Field Types
All Fields with Soil Moisture < 10% Excluded

	1		2		3		4	
	2/25/71 3,000 ft.	No. Observations & Range of Moisture	2/25/71 10,000 ft.	No. Observations & Range of Moisture	2/25/71 3,000 ft.	No. Observations & Range of Moisture	2/25/71	No. Observations & Range of Moisture
1. Bare, sampled day of flight, Phoenix	-0.66	(16) 10 - 33	-0.23	10 - 29 (22)				
2. Bare, Imperial only	-0.46	11 - 36 (22)	-0.29	11 - 36 (25)	-0.42	11 - 36 (24)		
3. Bare, all fields Phoenix	-0.50	10 - 32 (30)	-0.12	10 - 31 (41)			-0.38	10 - 29 (33)
4. Bare, leveled, Imperial	-	-	-	-			-	-
5. Bare, leveled, Phoenix	-0.38	10 - 32 (16)	-0.23	10 - 31 (17)			-0.35	10 - 29 (18)
6. Bare, furrowed, Imperial	-0.68	19 - 38 (13)	-0.13	19 - 36 (15)	-0.65	19 - 37 (15)		
7. Bare, furrowed, Phoenix	-0.78	13 - 29 (14)	-0.34	12 - 28 (24)			-0.89	11 - 25 (15)
8. Bare, loam, Phoenix	-0.62	13 - 25 (6)	-0.59	13 - 25 (6)			-0.95	10 - 19 (7)
9. Bare, laveen loam, Phoenix	-	-	-	-				
10. Bare, sandy loam, Phoenix	-0.15	18 - 22 (3)	-0.15	18 - 22 (3)			-0.86	15 - 18 (4)
11. Bare, clay loam, Phoenix	-0.26	10 - 33 (17)	0.05	10 - 31 (22)			-0.39	10 - 29 (17)
12. Bare, sandy clay loam, Phoenix	-	-	-0.34	13 - 27 (7)			-	-
13. Bare cloddy, Phoenix	-	-	-	-				
14. Vegetated (>50% coverage)	-0.48	10 - 28 (16)	-0.51	10 - 28 (18)				

Table 3 (continued)

Correlation Coefficient for Selected Field Types
All Fields with Soil Moisture $\lessdot$ 10% Excluded

	1		2		3		4	
	2/25/71 3,000 ft.	No. Observations & Range of Moisture	2/25/71 10,000 ft.	No. Observations & Range of Moisture	2/25/71 3,000 ft.	No. Observations & Range of Moisture	2/25/71	No. Observations & Range of Moisture
15. Vegetated ($\lessdot$ 50% coverage)	-0.58	17 - 26 (9)	0.02	12 - 28 (18)				
16. Bare, cloddy Phoenix	-	-	-	-				
Phoenix Sampled Day of Flight								
17. Bare, furrowed	-0.34	21 - 27 (7)	-0.70	10 - 35 (9)				
18. Bare, leveled	-0.70	10 - 35 (9)						
19. Bare, loam	-	-	-	-				
20. Bare, laveen loam	-	-	-	-				
21. Bare, sandy loam	-	-	-	-				
22. Bare, clay loam	-0.68	10 - 35 (14)	-	-				

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Figure 1

Microwave Brightness Temperatures vs. Soil Moisture
For Bare, Sandy Loam Fields at Phoenix, 2/25/71, 3,000 feet

CHART 171

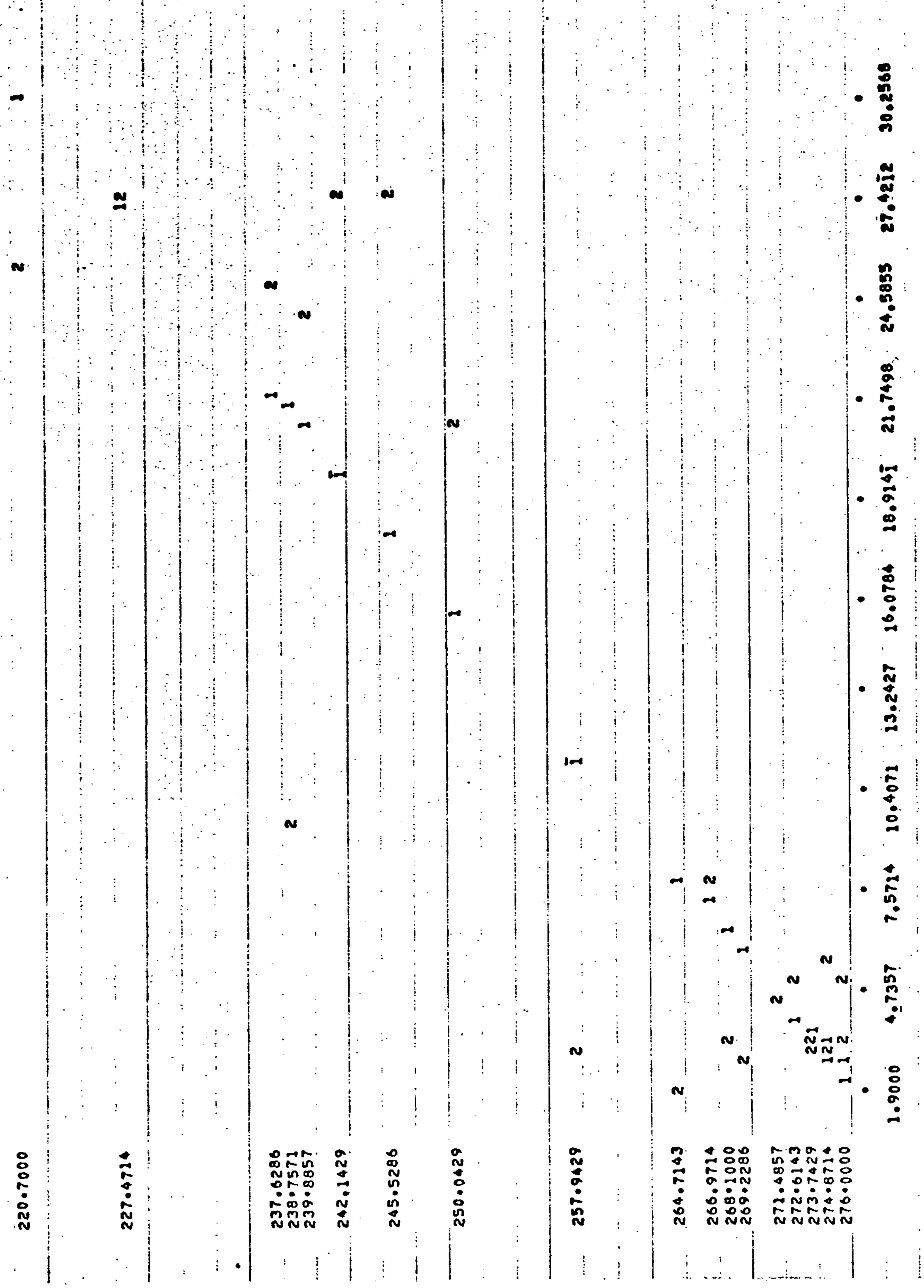

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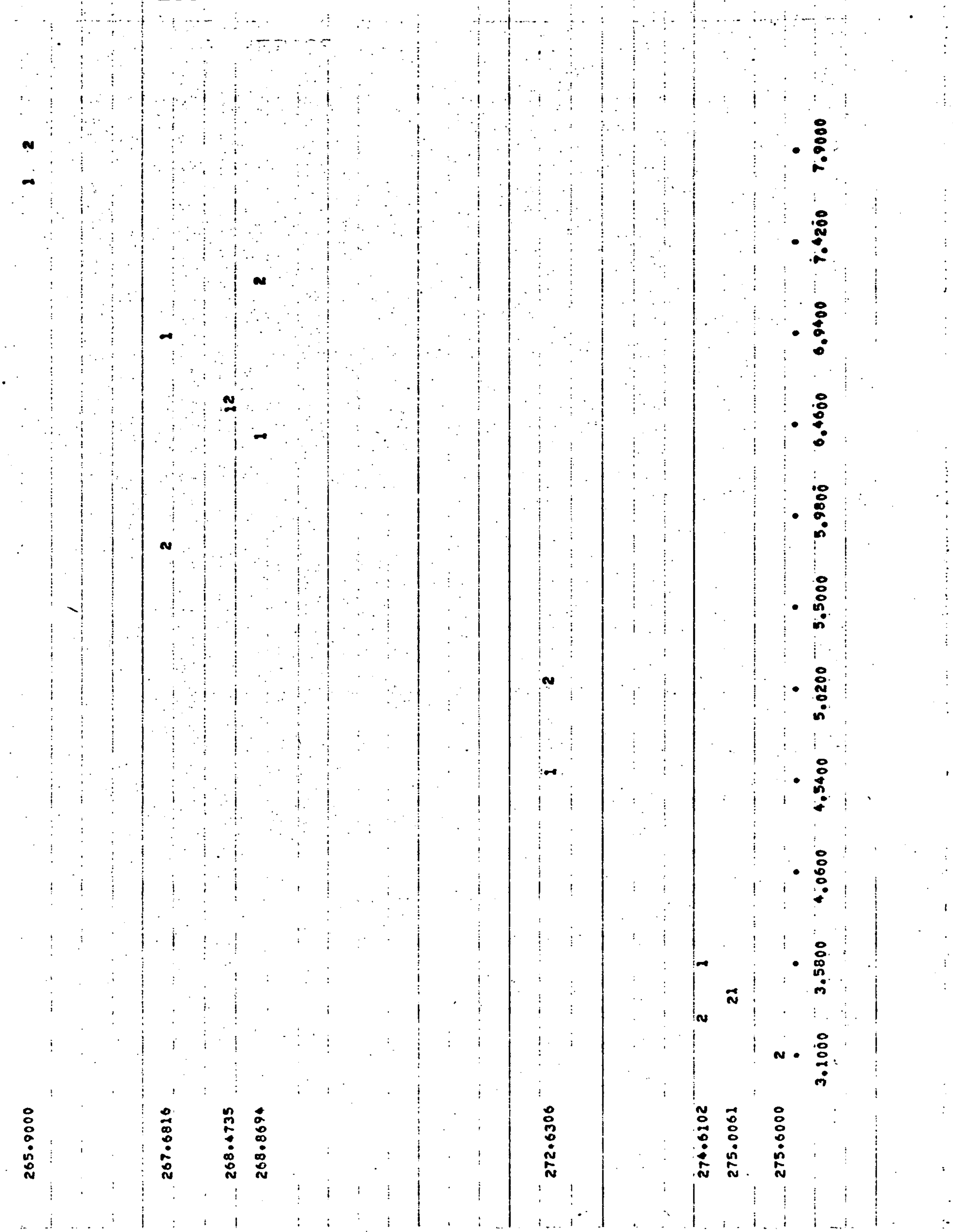
Figure 2

Microwave Brightness Temperatures vs. Soil Moisture
For Bare, Sandy Loam Fields at Phoenix, 2/25/71, 3,000 feet
(Low Soil Moisture Fields Only)



V. CONCLUSIONS

On the basis of these analyses, three major factors appear to affect the correlation between soil moisture and microwave brightness temperature. They are:

1. Altitude of the Aircraft - Good correlation was obtained during 3,000 ft. overflights of several field types. However, this same group of fields showed no correlation or poor correlation when sensing was done at 10,000 ft. on the same day as the lower altitude overflight.

2. Ability to Obtain Representative Soil Samples - Soil moisture determinations performed on samples which were not collected on the same day as the overflight, did not correlate well. It was also found that cloddy or freshly plowed fields showed no correlation. These fields would contain a mixture of wet and dry soil which is very difficult to sample. The time of sampling in respect to the time of sensing may be very important and should be considered in future analyses.

3. Vegetation - The low altitude flights over fields with $> 50\%$ vegetation coverage showed poorer correlation than bare fields.

Two factors which did not appear to affect the correlation were:

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1. Soil Texture - There were not sufficient data available to allow for statistical analysis of the effect of all major soil types. However, loam, sandy loam and clay loam all showed good correlation.

2. Surface Configuration - Furrowed fields and leveled fields both showed similar levels of good correlation.

It should be mentioned that the data analyses which were performed and resulting conclusions are the result of unbiased handling of all the data. Little or no effort was made to attempt a point by point examination of data which fell outside the general pattern of scatter. Exclusion of some of these points would definitely improve the correlation. However, insufficient descriptive information on individual fields exists to allow for legimate rejection or adjustment of most of these points.

The data obtained at Phoenix on 25 February 1971 is better than for other flights at Phoenix or flights over the Imperial Valley, California. No explanation for this difference can be made.

Respectfully submitted,

J. Rudolph Schrot

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Project Director

Approved:

Gilbert V. Levin

Gilbert V. Levin, Ph. D., President

APPENDIX I

Microwave Brightness Temperatures Obtained With 19 GHz Scanning Radiometer During 10,000 Foot Overflights of Phoenix, Arizona and Imperial Valley, California on 25 February 1971

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Microwave Brightness Temperatures Obtained During 10,000 Ft.
Overflights of Phoenix, Arizona and Imperial Valley, California
on February 25, 1971

		Brightness Temperature (°K)		
Field Number	Location	Mean Value For Field	Standard Deviation	Number Points/ Field
1	P A3115cb	267.6	5.6	7
2	P A3115cc	257.1	8.9	10
3	P A3122bc	250.8	37.4	8
4	P A3122cc	255.5	14.9	8
5	P A3122cd	258.2	6.4	9
6	P A3128ad	264.6	4.4	16
7	P A3128da	273.3	1.9	12
8	P A3128dd	274.4	5.5	12
9	P A3128db	270.1	2.1	9
10	P A3127bd	268.9	4.1	9
11	P A3133aa	270.7	3.9	12
12	P A3133ad	261.6	5.6	12
13	P A3133da	269.9	6.0	12
14	P A3133db	272.7	4.6	9
15	P A3133ac	269.0	3.1	9
16	P A3133bd	264.3	5.0	9
17	P A3133ba	264.4	2.2	9
18	P A3133bb	263.4	5.3	9
19	P A3133bc	256.3	11.4	9
20	P A3133cb	247.1	11.7	9
21	P A3133cc	250.3	11.5	9
22	P A3134bd	260.8	7.1	9
23	P A2104bb	260.1	8.8	9
24	P A2104ba	264.8	3.3	9
25	P A2104bd	267.4	5.7	9
26	P A2104bc	264.2	4.9	9
27	P A2104cb	259.1	5.6	12
28	P A2104ad	266.7	3.1	9
29	P A2103cb	267.3	5.4	10
30	P A2103cc	263.0	3.1	12
31	P A2109aa	266.0	7.1	9
32	P A2109ba	263.8	3.7	9
33	P A2109bb	260.8	4.2	9
34	P A2109bc	270.3	5.7	9
35	P A2109bd	260.8	4.7	9
36	P A2109cb	270.4	4.4	9
37	P A2109ca	268.7	3.5	9
38	P A2109dc	268.1	2.8	9
39	P A2110cc	270.1	3.9	9
40	P A2110cd	269.2	4.4	9

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Field Number	Location	Brightness Temperature (°K) Mean Value For Field	Standard Deviation	Number Points/ Field
41	A P2110ca	261.2	7.0	9
42	P A2116bb	258.1	8.0	9
43	P A2116bc	271.8	6.4	9
44	P A2116cb	239.3	14.8	9
45	P A2116cc	248.7	7.9	9
46	P A2116cd	262.6	4.4	9
47	P A2116ad	267.9	5.2	9
48	P A2116db	271.1	4.2	9
49	P A2116da	257.4	10.3	9
50	P A2115cc	261.8	9.8	9
51	P A2115cd			
52	P A2121ad			
53	P A2121ac			
54	P A2127ca			
55	P A2128da	263.8	2.9	13
56	P A2128db	266.6	4.7	13
57	P A2133bb	257.0	7.4	9
58	P A213bc	269.3	5.5	8
59	P A2133ba	249.2	5.6	9
60	P A2133bd	275.0	6.8	7
61	P A2133ab	262.1	8.6	9
62	P A2133ac	270.3	3.0	9
63	P A2133db	270.7	4.8	9
64	P A2133ad	269.4	4.3	9
65	P A2133da	270.9	7.3	9
66	P A2134bc	259.6	4.4	9
67	P A2134bd	267.8	3.6	9
68	P A2134ac	274.5	6.2	9
69	P A2134cd			
70	P A2134cc	263.4	6.8	9
71	P A1104db	242.0	8.9	9
72	P A1110bc	249.2	8.1	9
73	P A1109da	248.6	7.0	12
74	P A1109dd	255.8	8.0	12
75	P A1116bb	265.7	5.3	9
76	P A1116ba	258.7	3.5	9
77	P A1116ab	256.1	2.2	9
78	P A1116aa	260.1	3.7	12
79	P A1116cb	241.8	13.8	9
80	P A1116dc	257.8	3.7	9
81	P A116cd	265.9	4.4	9
82	P A1116cc	262.6	6.3	8
83	P A1121bb	251.6	16.6	9
84	P A1121ba	243.4	17.1	9
85	P A1121ab	242.1	7.6	9

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Field Number	Location	Brightness Temperature (°K) Mean Value For Field	Standard Deviation	Number Points/ Field
86	P A1121aa	236.6	11.8	9
87	P A1122bb	258.0	9.0	9
88	P A1122bc	276.6	4.2	9
89	P A1121ad	260.2	8.8	9
90	P A1121ca	260.1	5.4	9
91	P A1121cb	252.3	6.4	9
92	P A1121cc	262.2	7.5	9
93	P A1121cd	239.6	8.7	9
94	P A1128ba	265.0	5.8	9
95	P A1128bb	267.3	3.3	9
96	P A1128bc	296.6	6.2	9
97	P A1128db	249.3	3.6	9
98	P A1128ca	243.2	9.3	9
99	P A1128cd	239.4	16.6	9
100	P A1128dc	266.0	3.1	9
101				
102				
103				
104	P D1206cb	260.8	2.2	9
105	P D1206cc	256.8	4.5	9
106	P D1207bb	265.6	10.5	9
107	P D1206cd	268.2	4.4	9
108	P D1207ba	262.7	8.7	9
109	P D1207bd	268.4	5.6	9
110	P D1207ab	269.7	2.5	9
111	P D1206aa			
112	P D1207aa	269.2	3.8	9
113	P D1207ad	266.2	4.5	9
114	P D1205bc	266.7	3.7	9
115	P D1205cb	266.2	3.7	9
116	P D1205cc	267.8	4.5	9
117	P D1208bb	266.8	3.2	9
118	P D1205ca	272.1	3.3	9
119	P D1205cd	268.7	3.5	9
120	P D1205dc	266.2	4.1	9
121	P D1205dd	265.3	4.1	9
122	P D1204cb	272.0	3.5	9
123	P D1204cc	268.0	4.0	9
124	P D1204ca	272.0	2.8	9
125	P D1204cd	209.4	2.8	8
126	P D1209ab	263.2	5.8	9
127	P D1209ac	241.1	8.7	8
128	P D1209aa	268.7	2.7	9
129	P D1209ad	266.1	2.4	9
130	P D1203bb	269.0	4.5	9

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Field Number	Location	Brightness Temperature (°K) Mean Value For Field	Standard Deviation	Number Points/ Field
131	P D1203bc	265.2	4.4	9
132	P D1210bb	269.3	3.8	8
133	P D1210bc	269.8	3.1	9
134	P D1203ba	265.2	4.7	9
135	P D1203bd	265.3	3.3	9
136	P D1210ba	267.8	3.5	9
137	P D1210bd	269.2	3.8	9
138	P D1203ab	270.8	3.3	9
139	P D1203ac	266.9	2.6	9
140	P D1203db	267.7	5.1	9
141	P D1203dc	265.8	4.8	9
142	P D1203ad	273.2	3.2	9
143	P D1203da	273.0	3.2	9
144	P D1203dd	269.4	6.3	9
145	P D1201bb	254.5	11.0	9
146	P D1201cb	261.9	5.1	9
147	P D1201bc	247.2	6.7	5
148	P D1201ba	271.8	2.4	9
149	P D1201bd	274.0	4.7	9
150	P D1201db	267.9	3.8	9
151	P D1306bc	266.1	4.5	9
152	P D1306bb	257.4	7.1	9
153	P D1306cb	266.7	4.2	9
154	P D1306ca	262.9	6.0	9
155	P D1404ab	261.0	5.4	9
156	P D1404ac	247.2	4.4	9
157	P D1404aa	262.3	3.7	9
158	P D1404db	255.4	3.9	9
159	P D1404dd	259.3	9.1	9
160	P D1404dc	256.8	5.1	9
161	P D1409aa	263.7	2.5	9
162				
163	P D1410ab	267.0	2.5	9
164	P D1410ac	257.6	8.3	9
165	P D1410aa	271.3	4.9	9
166	P D1410ad	262.9	7.4	9
167	P D1411cc	264.4	8.4	9
168	P D1402ca	268.0	6.0	8
169	P D1402cb	264.1	8.4	9
170	P D1403ad	256.8	4.0	9
171	P D1403da	250.4	5.0	9
172	P D1411bb	266.1	5.1	7
173	P D1505ca	250.4	12.4	9
174	P D1505cd			
175	P D1504bc	238.1	18.5	9

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Field Number	Location	Brightness Temperature (°K) Mean Value For Field	Standard Deviation	Number Points/ Field
176	P D1504bb	256.8	4.3	9
177	P D1503ba	256.8	4.8	9
178	P D1503bd	265.4	5.8	9
179	P D1503ad	260.3	2.3	9
180	P D1502cb	268.9	2.0	9
181	P D1503da	261.8	3.6	9
182	P D1503db	268.3	4.3	9
183	P D1503dc	264.9	5.7	9
184	P D1503dd	262.0	3.0	9
185	P D1510ab	263.7	6.3	9
186	P D1510aa	258.8	2.1	9
187	P D1510ad	260.6	6.4	9
188	P D1511bb	253.6	9.1	9
189	P D1511ba	270.8	3.8	9
190	P D1511bc	248.8	9.8	9
191	P D1511bd	272.1	4.8	9
192	P D1511ac	270.1	2.5	9
193	P D1511ab	272.1	4.8	9
194	P D1511aa	262.3	8.8	9
195	P D1511ad	270.4	4.2	9
196	P D1512ad	268.3	4.4	9
197	P D1512aa	270.2	3.2	9
198	P D1505cb	263.8	7.6	9
199	P D1606bb	256.7	5.3	9
200	P D1607ba	269.3	2.1	9
201	P D1606dc	271.2	2.8	9
202	P D1606dd	274.7	4.0	9
203	P D1607aa	267.2	4.4	9
204	P D1607ad	253.7	9.0	9
205	P D1606da	269.3	4.9	7
135A	P D1203ca	264.0	2.7	9
207	IV 1	261.8	12.0	17
208	IV 2	268.0	7.1	21
209	IV 3	257.0	13.0	21
210	IV 4	248.8	9.7	21
211	IV 5	250.4	5.8	21
212	IV 6	261.4	9.8	28
213	IV 7	260.8	5.9	24
214	IV 8	257.4	5.0	24
215	IV 9	257.6	4.9	19
216	IV 10	266.5	7.0	22
217	IV 11	273.9	6.1	26
218	IV 12	274.0	6.6	20
219	IV 13	269.0	11.5	18
220	IV 14	269.8	10.4	18

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Field Number	Location	Brightness Temperature (°K) Mean Value For Field	Standard Deviation	Number Points/ Field
221	IV 15	261.6	7.3	18
222	IV 16	279.4	6.2	21
223	IV 17	275.7	8.2	21
224	IV 18	265.5	4.5	21
225	IV 19	260.5	5.9	20
226	IV 20	272.9	6.9	21
227	IV 21	273.2	7.2	21
228	IV 22	258.8	4.5	9
229	IV 23	263.4	6.3	9
230	IV 24	269.1	7.7	9
231	IV 25	268.7	2.7	9
232	IV 26	270.2	4.8	9
233	IV 27	271.1	4.4	12
234	IV 28	277.1	4.3	12
235	IV 29	267.3	9.4	12
236	IV 30	258.9	7.5	13
237	IV 31	262.7	4.6	9
238	IV 32	267.16	6.8	9
239	IV 33	269.7	5.5	9
240	IV 34	255.7	6.0	9
241	IV 35	266.7	4.6	9
242	IV 36	269.8	8.4	12
243	IV 37	272.4	2.4	12
244	IV 38	236.4	15.8	16
245	IV 39	279.2	5.0	12
246	IV 40	267.2	4.6	12
247	IV 41	265.5	4.7	12
248	IV 42	269.8	8.5	12
249	IV 43	275.4	4.3	8
250	IV 44	270.3	4.0	16
251	IV 45	270.3	4.8	16
252	IV 46	273.1	6.3	16
253	IV 47	229.6	22.6	16
254	IV 48	234.5	21.4	16
255	IV 49	272.3	8.5	12
256	IV 50	271.4	6.6	12

N.B.
P = Phoenix
IV = Imperial Valley

APPENDIX II

Microwave Brightness Temperatures Obtained with the 19 GHz Scanning Radiometer from 3,000 Foot and 10,000 Foot Overflights of Phoenix, Arizona; Imperial Valley, California and Weslaco, Texas During 1971

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The characteristic code which appears with these data was used in order to select and analyze certain field types by computer. The 14-character selection code is broken down as follows:

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1--Phoenix
| | | | | | | | | | | | └--Imperial Valley
| | | | | | | | | | | '--Cloddy or freshly plowed
| | | | | | | | | | '--Moisture samples collected
| | | | | | | | | |    same day as overflight
| | | | | | | | | '--Sandy clay loam soil
| | | | | | | | '--Clay loam soil
| | | | | | | '--Sandy loam soil
| | | | | | '--Laveen loam soil
| | | | | '--Loam soil
| | | | '--Furrowed
| | | '--Leveled
| | '--Vegetated (<50% coverage)
| '--Vegetated (>50% coverage)
'--Bare field
```

Sample fields for Phoenix are numbered consecutively 1 - 205 including 135A as number 206. Imperial Valley fields, 1 - 50, correspond to numbers 207 - 256.

Microwave Brightness Temperatures Obtained During
3,000 Ft. and 10,000 Ft. Overflight of
Phoenix, Arizona on 2/25/71 and 3/1/71

Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000 ft.	2/25/71 10,000 ft.	3/1/71 3,000 ft.	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
1		267.6	259.7	14.6	16.7	10001000001001
2		257.1	258.3	17.0	14.0	10001000001001
3	264.6	250.8	263.5	8.2	7.7	00110100001001
4	237.7	255.5	254.0	9.6	16.2	10001000101001
5		258.2		20.8		10001000101001
6	267.6	264.6	263.9	5.8	4.3	10010001001001
7	269.5	273.3	230.0	6.0	14.7	10010001000001
8	276.0	274.4	268.2	5.6	3.7	10010001000001
9	275.8	270.1	269.4	5.9	4.5	10001001000001
10		268.9		5.7		10001001000001
11	255.3	270.7	263.5	15.2	12.7	10001100000001
12	264.9	261.6	265.5	13.4	10.9	10001100000001
13	271.3	269.9	268.7	4.2	4.1	10001100000001
14	272.1	272.7	265.6	14.3	13.9	10001000010001
15	269.0	269.0	267.0	6.7	6.0	10001000100001
16	274.7	264.3	266.1	6.9	6.0	10010001000101
17	275.1	264.4	264.5	6.7	6.0	10010001000101
18		263.4	247.2			10010100000001

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Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
19		256.3	249.3	5.2		100011000000001
20		247.1	261.5	23.1		100010000100001
21		250.3	251.4	21.4		100010000100001
22		260.8				100011000000001
23	270.0	260.1	251.1	7.1	6.5	100100010000001
24	258.5	264.8	259.0	21.3	18.3	100010010000001
25	250.9	267.4	259.1	18.3	16.8	100010010000001
26	271.0	264.2	238.2	5.8		100010010000001
27		259.1	232.1	4.4		100010010000001
28	269.3	266.7	267.6	19.0	17.2	100010000010001
29		267.3	257.8	4.8		100101000000001
30		263.0	229.8	4.5	18.3	100101000000001
31	268.7	266.0	262.6	7.2	5.8	100100001001001
32	275.3	263.8	260.5	7.7	6.5	100100000101001
33		260.8	256.1	13.6		100010000011001
34		270.3	255.2	16.9		100010000011001
35	276.3	260.8	263.9	5.9	5.0	100100000101001
36		270.4	250.5	4.8		100010000011001
37	265.7	268.7	257.2	18.3		010100000101001
38	273.8	268.1	213.8	8.5	21.5	100100000101001
39		270.1	261.3	4.8	4.4	100100000011001
40		269.2		8.3		100100000011001
41		261.2		7.3		100100000101001
42		258.1	259.4	14.7		100010000011001
43		271.8	259.7	13.5		100010000011001
44		239.3	243.7		26.6	100100000101001
45		248.7	246.3			100100000101001
46	264.5	262.6	257.1	19.1		010010000101001
47		267.9	258.1	8.7		100100000101101
48	275.7	271.1	265.3	6.9	5.9	100100000101101
49	275.8	257.4	264.6	8.0	6.7	100100000101101
50		261.8		15.9	32.1	010100000101001
51				18.4	13.9	010010000101001
52	198.7		243.8	32.8	29.0	100100000101001
53	201.2		225.7	12.1	29.1	100100000100001
54				10.9		100010000100001
55	246.5	263.8	249.6	25.9	23.6	100010000100001
56	245.1	266.6	246.0	27.6	24.0	100010000101001
57		257.0		6.7		100010000100001
58		269.3		7.5		100010000100001
59	273.7	249.2	265.2	6.6	6.5	100010000100001
60	238.9	275.0	250.6	24.1	24.8	100010000101001
61	275.2	262.1	267.0	6.8	6.0	100010000100001
62	276.5	270.3	270.1	8.7	7.0	100010000100001
63	241.8	270.7	255.3	27.7		100010000101001
64	272.8	269.4	267.5	6.4	6.7	100010000100001
65	249.5	270.9	258.3	21.1	22.4	100010000101001
66		259.6	265.8	6.8	7.1	100010000100001
67		267.8		7.8		100010000100001
68		274.5		12.2	6.3	100010000100001
69				9.7		100100000100001
70		263.4	266.7	9.2		100100000100001
71	272.6	242.0	271.0	16.7	17.2	001100000100001
72		249.2	266.8	13.4	9.7	100100000100101

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Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
73	257.4	248.6	258.3	20.0		010010000100001
74	260.1	255.8	252.5	18.3	16.8	010010000100001
75		265.7	254.2	31.4		100100000100001
76	234.6	258.7	260.1	28.6	25.0	100100000101001
77	251.5	256.1	262.7	29.0		100100000101001
78	259.3	260.1	263.6	28.3	20.2	100100000101001
79		241.8	260.3	21.5		010100000100001
80	242.9	257.8	262.1	25.7	23.1	100100000101001
81	224.8	265.9	251.8	25.7	22.3	100100000101001
82		262.6	247.6	7.7	23.3	100100000100001
83		251.6	255.2	24.2	18.7	100100000100001
84	256.3	243.4	260.0	22.2	17.9	100100000101001
85	237.2	242.1	260.6	25.1		100010000101001
86	261.2	236.6	260.5	18.3		100100000100001
87		258.0		6.4		100100000100001
88		270.6		6.3		100100000100001
89	271.2	260.2	264.1	17.5		010100000011001
90	226.8	260.1	233.6	27.5		100010000011001
91		252.3	246.2	5.2		100010010010001
92		262.2	258.9	4.3	4.1	100100010010001
93	272.5	239.6	265.5	5.1	5.0	100010010010001
94	274.9	265.0	266.1	3.4	3.4	100010010010001
95		267.3	259.0	3.0	4.4	100100010010001
96		269.6	250.2	12.2	7.7	001010010010001
97	247.5	249.3	260.5	21.4		010101000001001
98	220.7	243.2	236.0	25.5	19.7	100011000001001
99		239.4	265.9	6.8		100100000101001
100	275.0	266.0	267.8	6.1	5.0	100100000101101
101						000000000001001
102						000000000001001
103						000000000001001
104	267.7	260.8	265.7	3.6	3.5	100011000001001
105	273.0	256.8	267.1	3.3	3.1	100011000001001
106	257.8	265.6	252.6	3.3	4.2	100011000001001
107	272.8	268.2	263.6	4.2	3.5	100101000001001
108	273.1	262.7	264.4	3.5	2.5	100011000001101
109		268.4		3.2	2.6	100011000000001
110	269.8	269.7	263.7	8.4		010011000000001
111				3.6		100101000001101
112	268.7	269.2	260.3	2.9	4.4	100011000001001
113		266.2		3.2		100011000001001
114	266.7	266.7	264.6	4.6		100101000001001
115	269.0	266.2	265.1	6.3	5.0	001101000001001
116	273.8	267.8	268.2	5.7	5.0	100011000001001
117	268.6	266.8	262.6	10.1		010011000001001
118	268.6	272.1	266.9	6.0	5.0	100101000001101
119	273.7	268.7	267.8	5.6	5.0	100101000001101
120	267.3	266.2	264.1	14.6	22.5	010101000001001
121	274.1	265.3	268.8	5.9	10.1	100101000001101
122	273.2	272.0	269.5	3.9	4.1	100100100001101
123	272.3	268.0	267.4	5.5	5.0	100100100001101
124	269.2	272.0	265.9	8.4	6.1	100100100001101
125	273.4	269.4	269.1	8.0	5.0	100100100001001
126	268.4	263.2	267.8	5.9	5.0	100100100001001

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Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
127		241.1		6.6		10010010001001
128	266.9	268.7	264.7	5.1	4.5	10010010000001
129		266.1		9.9	11.4	00101010000001
130		269.0		4.9		10010100000001
131	261.7	265.2	255.5	5.8		10010100000001
132	269.4	269.3	263.2	7.3	4.5	10010010000101
133		267.8		4.2	4.0	10001010000001
134		265.2		5.9		10010100000001
135	268.3	265.3	266.1	4.7	7.3	10010010000001
136	267.4	267.8	261.4	4.8	4.0	10010010000101
137		269.2		5.1		10001010000001
138		270.8		5.1		10010100000101
139	272.2	266.9	267.1	4.9	4.0	10010100000001
140	272.9	267.7	266.7	9.6	6.9	10010100000001
141	275.8	265.8	267.2	6.2	4.3	10010010000001
142	268.6	273.2	244.6	7.9	11.4	00101010000001
143	274.6	273.0	261.6	4.6	3.9	10010010000001
144	274.2	269.4	264.9	6.1	5.5	10001010000001
145	260.0	254.5		5.2		10010010000001
146	260.0	261.9	212.5	4.5	18.0	10001010000001
147	274.2	247.2	259.5	11.9	4.6	10010010000001
148		271.8		5.0		10010010000001
149	273.5	274.0	262.6	4.9	4.8	10010010000001
150	271.3	267.9	260.2	4.6	4.0	10010010000101
151	259.6	266.1	248.6	4.8		10010010000101
152		257.4		4.9	3.2	10010010000101
153	267.0	266.7	254.9	4.9	4.3	10010010000101
154	265.0	262.9	255.0	5.4	3.7	10010010000101
155		261.0		1.7		10001001001101
156	274.6	247.2	264.8	3.3	1.5	10001001001001
157		262.3		8.9		10001000001001
158	268.4	255.4	262.8	6.6		10010001001001
159	265.9	259.3	256.0	7.9	4.7	10001001001001
160	275.6	256.8	263.1	3.1	1.6	10010001001001
161	264.5	263.7	257.6	1.9	1.6	10001100001001
162						00000000001001
163	276.0	267.0	263.6	5.2	4.1	10001000101001
164		257.6		4.6		10001000101001
165	271.2	271.3	260.5	4.6	3.2	10001000101001
166		262.9		4.7		10001000101001
167	268.1	264.4	257.4	10.2	10.5	10010000101001
168	270.7	268.0	256.3	11.7	11.3	01010000101001
169	263.1	264.1	259.7	15.0		10010000101001
170		256.8		8.2		10010000101001
171	254.1	250.4	252.2	20.8	18.1	01010000101001
172	262.2	266.1	258.7	19.1		01010000101001
173	273.4	250.4	260.6	9.9	8.4	10010000101001
174	273.8		261.7	8.4	7.0	10010000101001
175		238.1		8.3		10010000101001
176		256.8		7.7	5.3	10010000101001
177		256.8		7.4		10010100000001
178		265.4		7.0	7.1	10010100000001
179	258.9	260.3	247.1	18.8		00110100000001
180	274.6	268.9	261.2	5.1	4.5	10001100000101

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Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
181	265.3	261.8	256.4	20.1	14.9	10010100000001
182	262.6	268.3	256.7	22.1		10010100000001
183	261.1	264.9	256.2	20.0	13.9	10010100000001
184	262.4	262.0	257.1	23.6		00110100000001
185		263.7	252.4	23.0	15.0	00110100000001
186		258.8	249.0	23.9	17.9	00110100000001
187		260.6		23.9		00110100000001
188		253.6	253.9	21.9		00110100000001
189		270.8	262.6	4.1	3.3	00101100000001
190		248.8		23.7		00110100000001
191		272.1		3.1	3.3	10001100000001
192		270.1		5.2	3.1	10001100000001
193		272.1	263.3	5.5	4.0	10001100000001
194		262.3	260.9	7.8	5.0	10001100000001
195		270.4		5.1	2.8	10001100000001
196		268.3		8.9		10010100000001
197		270.2	260.1	8.3	4.9	10010100000001
198	271.8	263.8	260.3	7.9	3.7	10010100000001
199		256.7		8.3		10010100000001
200		269.3	263.7	6.1	3.0	10001100000001
201	273.3	271.2	265.4	8.7	4.0	10010100000001
202	269.3	274.7	261.8	7.8	3.9	10010100000001
203		267.2	263.4	9.1	4.5	10010001000001
204		253.7		6.7		10010001000001
205	245.4	269.3	254.2	22.3	16.2	10010001000001
135A	266.7	264.0	236.6	9.6		01010010000001

Microwave Brightness Temperatures Obtained During
3,000 Ft. and 10,000 Ft. Overflight of
Imperial Valley, California on 2/25/71

Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
207	271.0	261.8	267.9	2.95		00110000001010
208	262.5	268.0	261.6	22.18		01010000001010
209	226.7	257.0	228.2	35.35		10001000001010
210	237.7	248.8	241.8	37.00		00001000001010
211	241.1	250.4	241.1	36.13		00000000001010
212	252.4	261.4	253.4	30.85		10001000001010
213		260.8		4.43		10010000001010
214		257.4		6.48		10010000001010
215	274.2	257.6	271.6	21.43		10001000001010
216	277.2	266.5	272.3	19.38		10001000001010
217	281.4	273.9	274.3	7.43		10000000001010
218	280.0	274.0	273.9	6.15		10000000001010
219	282.6	269.0	273.2	11.10		10000000001010
220	282.7	269.8	272.8	11.70		10000000001010

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Field No.	Mean Brightness Temperature (°K) 2/25/71 3,000	2/25/71 10,000	3/1/71 3,000	Soil Moisture (%) 2/25/71 2/23/71	3/1/71	Characteristic Code
221	256.3	261.6	254.8	22.48		0100100000101 0
222	281.6	279.4	273.8	13.88		1000000000101 0
223	282.7	275.7	273.6	13.70		1000000000101 0
224	266.9	265.5	261.3	24.90		0010100000101 0
225	262.6	260.5	260.9	22.75		0010100000101 0
226	276.2	272.9	271.0	24.45		1000100000101 0
227	277.5	273.2	270.2	23.98		1000100000101 0
228		258.0	245.7	31.53		1000100000101 0
229		263.4	250.5	31.63		1000100000101 0
230		269.1		7.93		1000000000101 0
231		268.7		28.70		0011000000101 0
232	266.6	270.2	266.1	33.15		1000100000101 0
233	260.6	271.1	262.8	36.15		1000100000101 0
234	274.9	277.1	270.8	31.78		1000100000101 0
235	275.6	267.3	271.9	27.65		1000100000101 0
236	269.0	258.9	269.2	28.18		0101000000101 0
237		262.7		14.53		0011000000101 0
238		267.1		18.80		1001000000101 0
239		269.7		22.18		0011000000101 0
240		255.7		9.33		0101000000101 0
241	266.6	266.7	269.0	13.60		0101000000101 0
242	278.9	269.8	272.8	6.15		1000000000101 0
243	278.8	272.4	272.1	5.73		1000000000101 0
244	209.3	236.4	212.9	23.00		1000000000101 0
245	282.2	279.2	274.2	13.88		1000000000101 0
246	270.6	267.2	270.4	22.00		0011000000101 0
247	258.8	265.5	260.1	26.30		0011000000101 0
248	276.4	269.8	272.6	21.45		1000100000101 0
249	272.6	275.4	271.4	20.55		0011000000101 0
250	271.6	270.3	272.1	12.78		0101000000101 0
251	270.1	270.3	270.1	27.68		1000100000101 0
252	270.6	273.1	268.3	25.40		1000100000101 0
253	200.1	229.6	208.4	31.15		1000000000101 0
254	209.0	234.5	215.6	24.48		1000000000101 0
255	273.3	272.3	272.0	19.00		1000000000101 0
256	274.7	271.4	272.2	17.18		0011000000101 0

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Microwave Brightness Temperatures Obtained During
3,000 Ft. Overflights of Weslaco, Texas
on 3/1/71 and 3/2/71

Field No.	Mean Brightness Temperature (°K) 3/1/71	3/2/71	Soil Moisture % 0-1 Inch Depth	0-6 Inch Depth	Characteristics
53	244.500	246.840	44.300	39.500	Cabbage
55	250.600	266.960	44.300	39.500	Cabbage
57	276.600	292.400	15.700	23.300	Corn Seedlings
58	277.900	299.500	13.800	21.700	Bare, Burrowed Sm. Cld.
61	280.900	295.650	28.100	28.100	Bare, Burrowed Sm. Cld.
63	284.200	293.010	23.500	28.700	Bare, Burrowed Sm. Cld.
64E	278.700	274.120	0.0	0.0	Onions
64W	278.700	295.460	0.0	0.0	Onions
66	275.300	292.410	0.0	0.0	Onions
67	270.800	288.570	0.0	0.0	Onions
68	257.400	268.320	0.0	0.0	Cabbage
70	279.900	299.670	0.0	0.0	Bare
77	272.800	290.190	0.0	0.0	Vegetated
79	284.900	298.700	7.800	18.600	Bare, Dp. Plowed Lg. Cl.
81	276.800	292.030	0.0	0.0	Onions
83	282.800	301.220	5.700	17.400	Bare, Dp. Plowed
85	270.700	283.980	0.0	0.0	Oats
89A	0.0	289.290	6.800	16.800	Bare
89B	0.0	277.540	6.800	16.800	Old Cabbage + Weeds
89D	0.0	286.880	6.800	16.800	Old Caggabe + Weeds
91	0.0	284.780	27.800	32.400	Spinach
94	0.0	276.560	0.0	0.0	Bare
96W	0.0	277.600	6.400	14.400	Bare, Furrowed Lg. Cld.
96E	0.0	247.800	0.0	0.0	Bare, Furrowed Lg. Cld.
97	0.0	269.930	8.500	20.700	Bare, Furrowed Sm. Cld.
99A	0.0	259.890	7.800	19.400	Bare, Furrowed Sm. Cld.
99C	0.0	298.510	7.800	19.400	Bare, Burrowed Sm. Cld.
100	0.0	286.690	0.0	0.0	Bell Peppers
101	273.800	282.840	0.0	0.0	Alfalfa
104	286.800	299.340	6.700	17.300	Bare, Furrowed Sm. Cld.
105	276.900	291.470	22.300	22.300	Bare, Furrowed Sm. Cld.
107	286.000	299.200	14.200	22.200	Bare, Furrowed Sm. Cld.
109	245.800	261.270	35.000	18.700	Bare, Irr. 3/1/71
111	285.600	299.110	8.400	22.800	Bare, Flat Crusted Sf.
113	288.200	300.670	10.100	22.600	Bare, Burrowed Lg. Cld.
116	286.000	299.370	16.000	21.000	Bare, Furrowed Sm. Cld.
117	276.100	293.420	0.0	0.0	Pasture
120A	255.600	267.330	35.000	0.0	Young Corn Plants
120B	246.600	257.310	35.000	0.0	Bare, Furrowed Sm. Cld.

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Field No.	Mean Brightness Temperature (°K) 3/1/71	3/2/71	Soil Moisture % 0-1 Inch Depth	0-6 Inch Depth	Characteristics
122	283.000	299.950	13.500	21.100	Bare, Furrowed Sm. Cld.
124	285.000	295.420	16.000	27.400	Bare, Furrowed Sm. Cld.
127	288.800	300.780	13.300	28.800	Bare, Furrowed Sm. Cld.
129	281.000	300.970	14.100	28.500	Bare, Furrowed Sm. Cld.
129A	255.800	248.410	49.000	50.300	Bare, Furrowed Sm. Cld.
131A	281.600	290.780	0.0	0.0	Bermuda Grass
131B	285.700	296.960	0.0	0.0	Stubble
132	285.300	300.220	8.200	17.200	Bare, Dp. Plowed Lg. Cl.
134	284.300	300.840	9.100	20.800	Bare, Furrowed Sm. Cld.
136	285.200	299.090	23.800	25.700	Bare, Furrowed Sm. Cld.
139	284.800	297.140	25.200	25.300	Bare, Burrowed Sm. Cld.
140	276.000	288.830	30.800	30.800	Sm. Sorghum Plants
143A	282.300	302.900	9.800	20.000	Bare, Dp. Plowed Lg. Cl.
143B	287.300	299.800	13.000	19.200	Bare, Flat Small Clod
143C	282.700	294.010	15.000	16.500	Bare, Furrowed Sm. Cl.
144	283.300	298.610	15.000	25.500	Bare, Furrowed Sm. Cl.
146A	280.900	296.400	0.0	0.0	Bare
148	261.700	276.650	0.0	0.0	Vegetated

APPENDIX III

Textural Analysis of Imperial Valley and Phoenix Area Soils

Table 1
Textural Analysis of Imperial Valley & Phoenix Area Soils

Soil Classification	Replicate	% Sand	% Silt	% Clay	Soil Texture
Imperial Valley East	A	75	13	12	Sandy Loam
	B	77	11	12	Sandy Loam
	C	77	11	12	Sandy Loam
	Average	76	12	12	Sandy Loam
Imperial Valley West	A	27	43	30	Clay Loam
	B	27	43	30	Clay Loam
	C	28	42	30	Clay Loam
	Average	27	43	30	Clay Loam
2F	A	54	28	18	Sandy Loam
	B	56	26	18	Sandy Loam
	C	58	26	16	Sandy Loam
	Average	56	27	17	Sandy Loam
4E	A	46	24	30	Silty Clay Loam
	B	44	26	30	Clay Loam
	C	44	26	30	Clay Loam
	Average	45	25	30	Clay Loam
5M	A	89	6	5	Sand
	B	87	8	5	Loamy Sand
	C	88	8	4	Sand
	Average	88	7	5	Sand
7H	A	20	46	34	Silty Clay Loam
	B	18	48	34	Silty Clay Loam
7D	C	20	44	36	Silty Clay Loam
	Average	19	46	35	Silty Clay Loam

Table 1 (continued)

Textural Analysis of Imperial Valley & Phoenix Area Soils

Soil Classification	Replicate	% Sand	% Silt	% Clay	Soil Texture
3L	A	48	34	18	Loam
	B	48	34	18	Loam
	C	48	34	18	Loam
	Average	48	34	18	Loam

MECHANICAL ANALYSIS OF SOILS BY THE HYDROMETER METHOD

Procedure.

1. Weigh out 100 g of air-dry sandy soil (light textured) or 50 g of clay or silt loam soil (medium to heavy textured). Transfer to a 250 ml beaker. Cover with water. Add 5 ml of 10% Calgon and allow to stand over-night.

2. Transfer to a metal dispersion cup and fill about 2/3 full with H_2O.

3. Place dispersion cup on mixer and stir for 5 minutes.

4. Transfer contents from the dispersion cup to a Bouyoucos Cylinder.

5. Place the hydrometer in the suspension very gently and bring to volume with distilled water. If 50 g of soil were used, bring the suspension to the lower mark (1130 ml). If 100 g were used bring the suspension to the upper mark (1205 ml).

6. Carefully remove the hydrometer and shake the cylinder thoroughly by placing a large stopper over mouth of cylinder and inverting several times to obtain a uniform suspension.

7. Place cylinder on a table and note the time. Carefully but quickly place the hydrometer in the suspension At the end of 40 seconds take the hydrometer reading.

8. Remove the hydrometer and take the temperature of the suspension being careful not to disturb the suspension.

9. Take the second hydrometer and temperature readings at the end of two hours.

Calculations.

1. At the end of 40 seconds, the sand fraction has settled (0.05 mm and larger), but the silt plus clay is still in suspension. A 1 hour reading would indicate the 5 micron or smaller material in suspension. A 2 hour reading would indicate the 2 micron material (clay). For every degree F above 67°, 0.2 of a hydrometer graduation must be added to the hydrometer reading. For each degree below 67°F subtract 0 2 of a graduation

A. 40 Sec. Reading

$$\frac{\text{40 second hydrometer reading}}{\text{weight of sample}} \times 100 = \text{\% Silt and Clay}$$

$$100 - (\text{\% Silt \& Clay}) = \text{\% of Sand}$$

B. 2 Hour Reading

$$\frac{\text{2 hour hydrometer reading}}{\text{weight of sample}} \times 100 = \text{\% Clay}$$

C. 100 - (% Sand + % Clay) = % of Silt

D. Temperature Correction

$C = 0.2\ (T-67)$

(C is the hydrometer correction. Round off to nearest whole number. T is the temperature of suspension in °F)

2. Refer to Figure 1 for the textural classification.

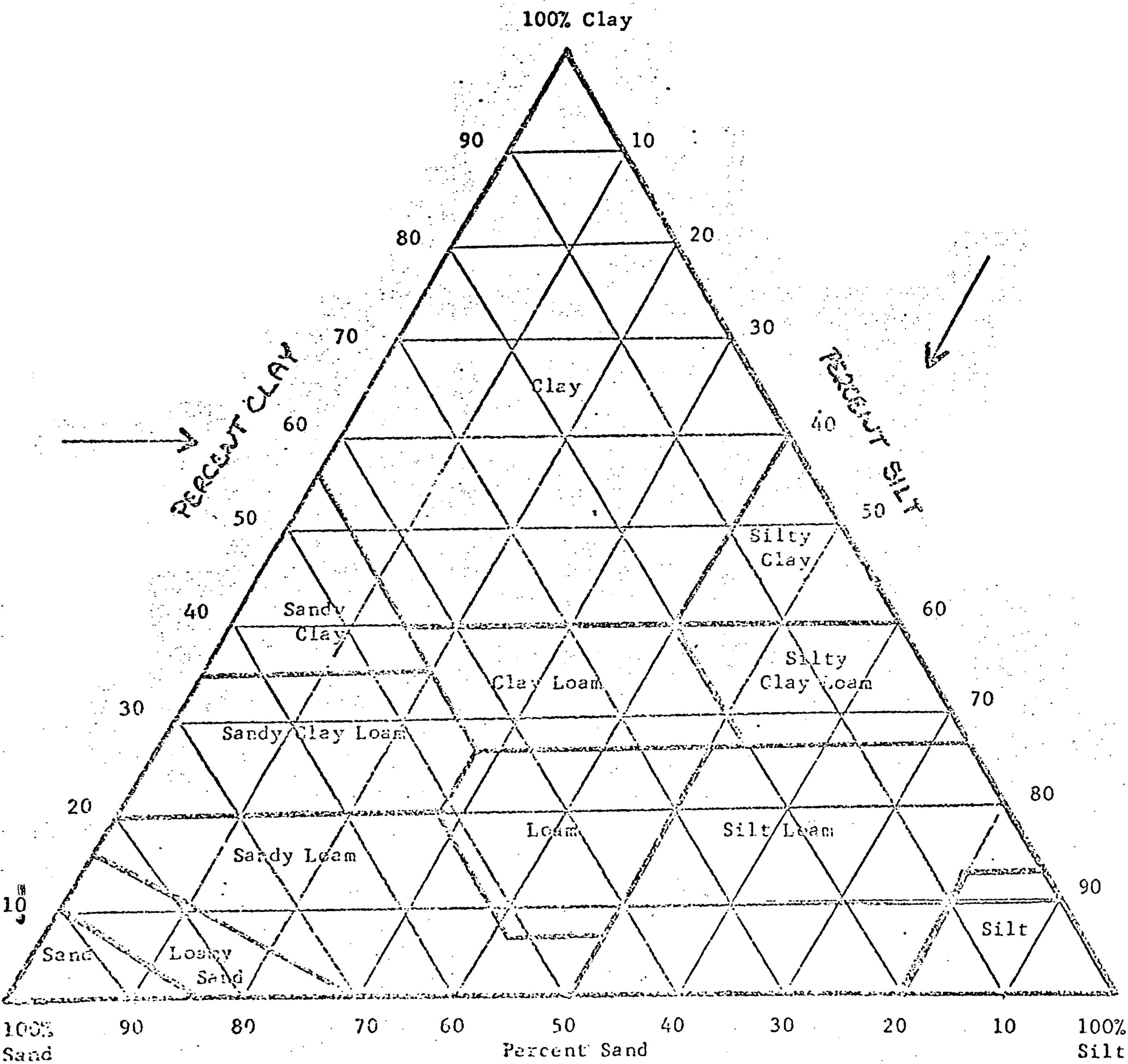

FIGURE 1
GUIDE FOR TEXTURAL CLASSIFICATION